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Encounter With Uranus

The *first* discovery of Uranus came more than two centuries ago, when not even the Earth was fully explored, and the true scale of the solar system was not yet imagined.

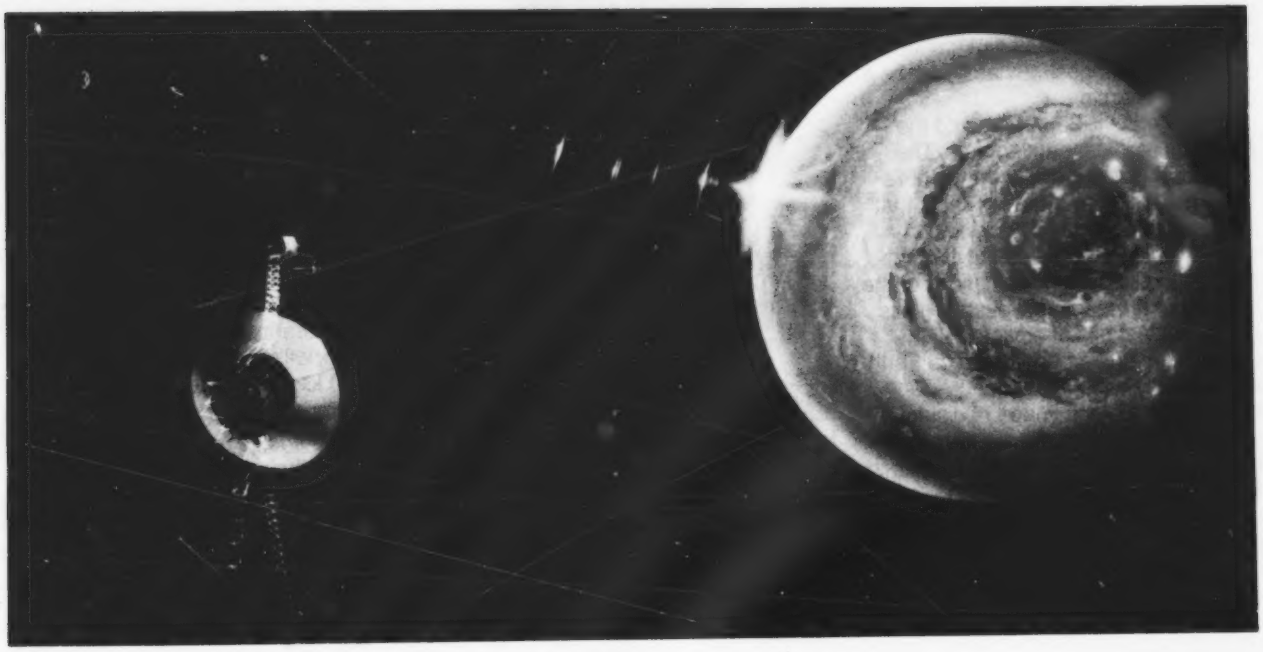
On the night of March 13, 1781, the English musician and amateur astronomer William Herschel was conducting a survey of the sky with his six-inch reflecting telescope (he had determined "never to pass by any, the smallest, portion of [the heavens] without due investigation"), when he stumbled across an object of "uncommon appearance" between the constellations Auriga and Gemini. Supposing it to be a comet, Herschel reported his find to the international astronomical community, but within a few months the object was recognized as something much rarer and more important—a "new" world, circling the Sun at nearly twice the distance of the farthest known planet, Saturn.

Uranus' *second* discovery—a more revealing one—is happening right now, in our time. Four planets and nearly two billion miles away from its starting point on the beaches of Florida in 1977, the Voyager 2 spacecraft is approaching a world so pale and distant that not even 200 years of observation have much improved our understanding of it. Voyager's next stop, in January 1986: Uranus, the seventh planet from the Sun.

The Story So Far

The two Voyager spacecraft are halfway through a "grand tour" of the giant gas planets of the outer solar system—Jupiter, Saturn, Uranus, and Neptune. Until the time of the Voyager launches, only the inner, Earthlike planets had been photographed and explored in any detail. Jupiter and Saturn had been only very briefly surveyed by two modestly equipped Pioneer probes, and Uranus and Neptune were mysterious points of light in the telescope.

It happened that in 1977, for the first time since Thomas Jefferson was president, the large outer planets were



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aligned in their orbits around the Sun so that, by using the gravity field of one planet to hurl it on to the next, a spacecraft could be launched to pass by all four of them over the course of a 12-year mission.

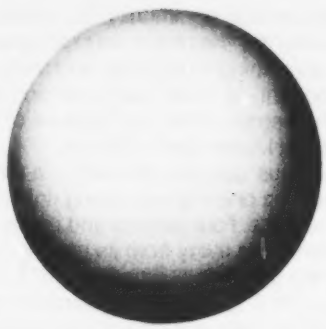
Voyagers 1 and 2 left Earth in September and August, 1977, respectively (Voyager 2 took a more roundabout route to Jupiter). They arrived at Jupiter in 1979, where they found, among other surprises, an entirely unknown ring around the planet's middle, a brightly colored atmosphere swirling with hurricanes, and exploding volcanoes on the sulphurous moon Io.

The explorations of Saturn in November 1980 and August 1981 were equally spectacular. Voyager 1 saw the planet's ring system to be much more complicated than had been imagined, with thousands of individual strands circling its equator. The Saturnian satellites had a few surprises as well—there were small "shepherding" moonlets whose gravity controlled the shape of the rings, and there was Phoebe, whose unusual dark surface and rotation suggested that it may be a captured asteroid.

For Voyager 1, Saturn marked the end of its planetary adventures. The spacecraft passed under the planet's south pole, getting a gravity boost that shot it upward, out of the plane of the solar system. As it heads out, though, conducting its own investigations of the interplanetary medium, Voyager 1 has had a few last bits of advice for its companion. Project engineers on Earth occasionally have the spacecraft photograph the tiny image of distant Uranus in order to calibrate the planet's brightness at different sun angles—because, going into its encounter with Uranus, Voyager 2 needs all the information it can get. Until now, the spacecraft has had three other probes blazing the trail ahead of it. At Jupiter, for example, Pioneer's discovery of intense radiation belts charted a safe course for the Voyagers, and Voyager 1's discovery of a Jupiter ring allowed the second spacecraft to be reprogrammed for closer study.

This time, Voyager 2 is traveling alone into unexplored territory.

Oberon



Titania

Umbriel

Ariel

Miranda

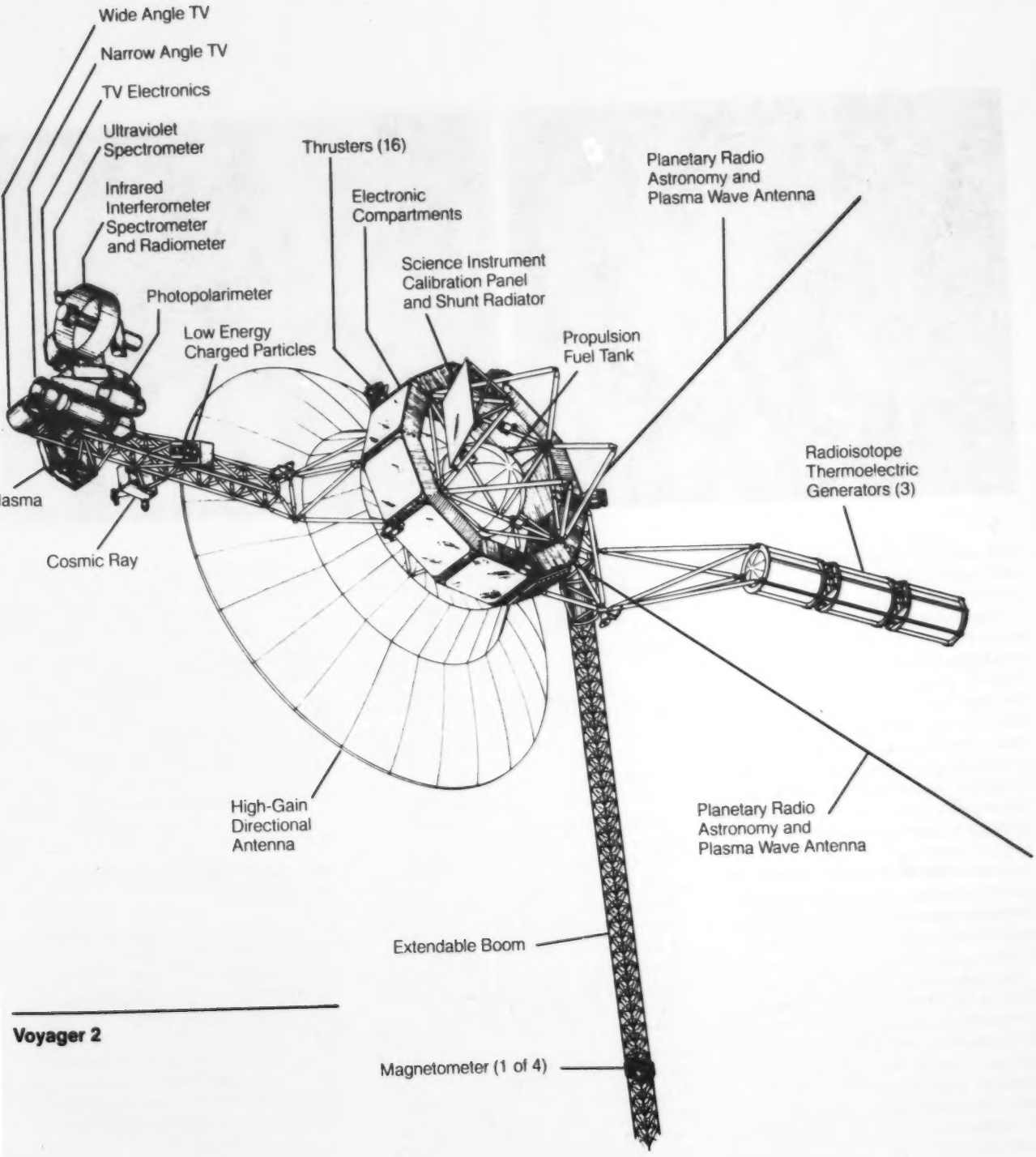
The five known moons of Uranus, in order of their distance from the planet. Miranda is the smallest, with an estimated diameter of 500 kilometers. Ariel has a diameter of about 1,330 km; Umbriel, about 1,110 km; Titania, abotu 1,600 km; and outermost Oberon, about 1,630 km.

A Pale and Distant World

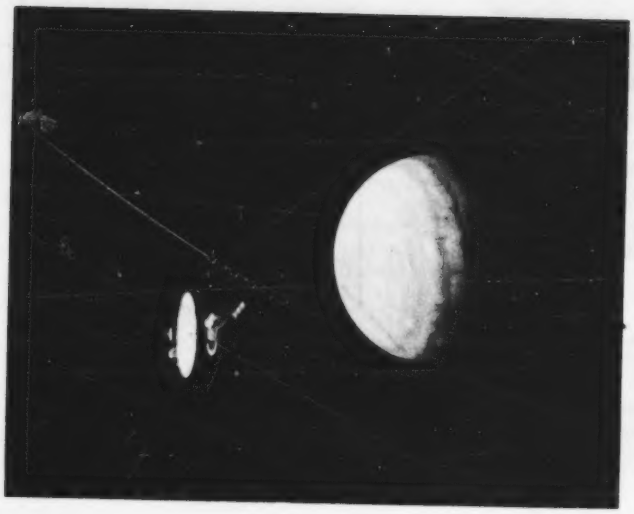
A few facts and oddities about the first "discovered" planet: The Uranian year is long—it takes the planet 84 Earth-years to circle the Sun. Uranus orbits at some 19 times the Earth-Sun distance, where it receives only 1/360 of the solar radiation we do. Another way of measuring the distance is in light-hours. At the time of the Voyager 2 flyby, it will take a radio signal, traveling at the speed of light, 2 hours, 45 minutes to reach Earth from Uranus.

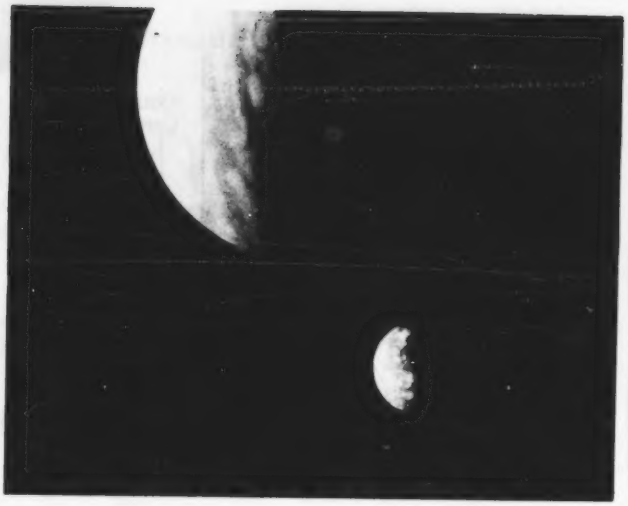
Like the other large planets of the outer solar system—Jupiter, Saturn, and Neptune—Uranus is believed to be mostly composed of gas. The "surface" that we see in a telescope is in reality the planet's atmosphere, which in this case is a soft aqua color, both in Earth-based views and in early Voyager photos. The reason for that coloring is not entirely known, although one explanation is that methane in the atmosphere could absorb red light, leaving blue and green.

Uranus and Neptune are near twins, intermediate in size between the rocky Earthlike planets and Jupiter and Saturn. Uranus is slightly the larger of the two, with a diameter of about 51,000 kilometers (km). It is four times


Wide Angle TV
Narrow Angle TV
TV Electronics
Ultraviolet Spectrometer
Infrared Interferometer Spectrometer and Radiometer
Photopolarimeter
Low Energy Charged Particles
Thrusters (16)
Electronic Compartments
Science Instrument Calibration Panel and Shunt Radiator
Propulsion Fuel Tank
Planetary Radio Astronomy and Plasma Wave Antenna
Radioisotope Thermoelectric Generators (3)
Cosmic Ray
High-Gain Directional Antenna
Planetary Radio Astronomy and Plasma Wave Antenna
Extendable Boom
Magnetometer (1 of 4)

Voyager 2





wider and fifteen times heavier than the Earth, giving it a density only slightly greater than water.

If Jupiter and Saturn have outer atmospheres made mostly of hydrogen and helium, scientists believe that Uranus and Neptune are what those two giants would look like if these lighter elements were mostly stripped away. What remains would be some hydrogen and helium, along with such compounds as methane, ammonia, and ethane, and these have been seen or inferred in the atmosphere of Uranus. Beneath this cold atmosphere is believed to be a warmer mantle of partially melted ammonia, methane, and even water ices. Beneath that, warmer still, a rocky core is thought to exist.

Uranus is accompanied by five moons that we know of. In order of their distance from the planet, they are: Miranda, Ariel, Umbriel, Titania, and Oberon. Switch the order of Ariel and Umbriel, and you will also have the satellites arranged by size, with Miranda the smallest (about 500 km in diameter) and Oberon the largest (about 1,630 km). Uranus also has a ring system, discovered in 1977 when the light from a star passing behind the planet (as seen from Earth) was blocked momentarily. There are nine known rings, very narrow and very dark—as dark as ground-up charcoal.

Perhaps the most peculiar thing about this planet, which makes it different from any other that we know of, is its odd tilt. From our point of view, Uranus lies on its side, with its rotational axis and its orbital path nearly at right angles. As Voyager approaches the planet, it will be looking pole-on. Right now, it is midsummer in what is considered, by convention, the south of Uranus. One explanation that has been proposed for this strange tilt is that early in its history Uranus was struck by a fast moving Earth-sized body, whose enormous force literally knocked the planet on its edge.

Another peculiarity of Uranus is that, unlike the other gas planets, it does not appear to be radiating more heat than it absorbs—Uranus apparently has no internal energy source, which might make its weather systems quite different from those Voyager has seen at Jupiter and Saturn.

Voyager approaches Uranus' sunlit hemisphere (BB), then flies past Miranda at nearly the same time as it crosses the plane of the rings (CC). Passing around and behind the planet as seen from Earth (DD), the spacecraft looks back (EE) in the direction of Earth and the sun, whose light may deflect off small particles to make the rings appear bright.

November 1985: Approaching the Unknown

Voyager 2's encounter with Uranus began in early November 1985 when the resolution—or amount of detail in the returning spacecraft photographs—was already substantially better than the best Earth-based views. Because so very little is known about Uranus, this "Observatory Phase" is a valuable opportunity to learn more about the planet before the actual flyby on January 24, 1986.

Shortly after the Uranus observations began, Voyager 2 began

taking "movies" of the approaching planet—actually individual photographs taken every few minutes, for a period of 38 hours. In November and December, Voyager took a total of four movies; in January, before the actual close flyby, they will be taken weekly. The movies should give a clear picture of atmospheric motions over time, with increasingly better resolutions as the spacecraft approaches Uranus. (Each week, the spacecraft comes 8.8 million km closer to its target.)

One of the first questions to settle is the length of the Uranian day. Estimates vary as to how often the planet turns on its axis, but the most accepted number, pre-Voyager encounter, is 16 hours. If there are cloud features in the atmosphere that can be "tracked" through portions of one or more rotations in these observatory "movies," scientists should be able to get a fix on the length of the day. If Voyager's radio astronomy antennas pick up radio emission from the planet, the variability may also help to establish a rotation rate.

Another issue to be addressed by these movies is the nature of weather on Uranus. Going into the Voyager encounter, there was a real question as to whether discrete clouds will appear at all in visible wavelength pictures of the atmosphere. In the best Earth telescopes equipped with the most modern electronic image detectors, Uranus appears as nothing more than a fuzzy ball of light with no clearly discernible markings. The even higher resolution photos taken by Voyager prior to November 1985 were similarly featureless.

This may only partly have to do with the planet's remoteness. It may also be that Uranus has a naturally bland appearance. This world is much colder than the two others Voyager has visited—its cloudtops drop down to -200 degrees C. At these temperatures, thin, hazy methane clouds are likely to obscure from our view lower clouds of ammonia ice (if they exist).

Although Jupiter and Saturn show "belts" of swirling, turbulent cloud systems, Uranus' lack of an internal heat source and the tilt of its axis (which keeps one hemisphere in sunlight and the other in darkness for prolonged periods) may create different kinds of weather patterns. If there are no belts and zones, then storms on Uranus may be more Earthlike—sudden and random, like tropical hurricanes.

As Voyager approaches the planet, it will observe the disk of Uranus in visible, infrared, and ultraviolet light. The infrared spectrometer will be particularly useful in recording the planet's thermal energy balance, a critical factor in understanding how gases mix inside the sphere, and how Uranus relates with the distant Sun.

Dark Moons, Darker Rings

The Uranian moons are so tiny in Earth telescopes that virtually nothing is known about them. Herschel himself located the two largest—Titania and Oberon—within a few years of finding the planet, but the next two—Ariel and Umbriel—weren't detected until 1851, and it wasn't until 1948 (only half a Uranus year ago!) that the tiny innermost moon Miranda was spotted.

Astronomers believe they know the satellites' densities, based on their gravitational effects and their sizes,

which are estimated from telescopic measurement of their infrared brightness. The densities remain uncertain, however, until Voyager determines more accurately the diameters of the moons. All five satellites are thought to be relatively dark—not quite so dark as the rings (which reflect only 2% of the sunlight that strikes their surface), but dark nonetheless. One proposed explanation is that ultraviolet light from the Sun may react with methane mixed in with the surface ice to give the moons a reddish cast.

During the approach to Uranus, Voyager's cameras will take many images of the moons to assess their brightness and to more accurately determine their positions for determining and fine-tuning the spacecraft's trajectory. As Voyager gets closer to the planet, the rings and moons will fill up more of the camera's field of view. By late December, the rings will take up the entire frame.

Prior to the Voyager encounter, scientists remained unsure just how visible the dark, narrow rings of Uranus were going to be to the approaching spacecraft. There are several theories as to why the rings are as soot-dark as they are. They could be made of an intrinsically dark material, or we could be seeing only a very small cross-section from Earth. If the ring particles—most likely an orbiting swarm of ice, rock, and dust—are coated with methane, that could also darken their surfaces. Even if the rings don't show up in photographs taken during the approach, there will be a better opportunity to study them during the close flyby in the last week of January.

Voyager's "fields and particles" sensors, which measure magnetic fields and the presence of atomic particles, are also busy during the approach. Signs of auroral activity seen at Uranus' south pole suggest that the planet has a magnetic field, but this is not established. Both Jupiter and Saturn have large magnetic fields caused by fluid motion in their interiors; Uranus is expected to have one also. Voyager will be searching for radio emissions suggestive of a planetary magnetic field as it nears the planet. Then, about a day away from closest approach, the spacecraft is expected to cross a curving "bow shock" where the oncoming solar wind of charged particles meets Uranus' own magnetic field head-on. The fields and particles instruments will be listening.

Long-Distance Communications

Radio communications are critical for the Voyager mission. Unless the giant antennas of NASA's Deep Space Network (located in Spain, Australia, and California, for equidistant spacing around the turning Earth) can pick up the spacecraft's radio signal, the mission is useless—Voyager's reports of discoveries would go unheard. For the closest approach to Uranus, which lasts only a few hours, this network will be supplemented by an additional 64-meter antenna at the Parkes Radio Observatory in Australia. Also, as many as four large antennas at a time will be "arrayed" so that their signals can be combined into one.

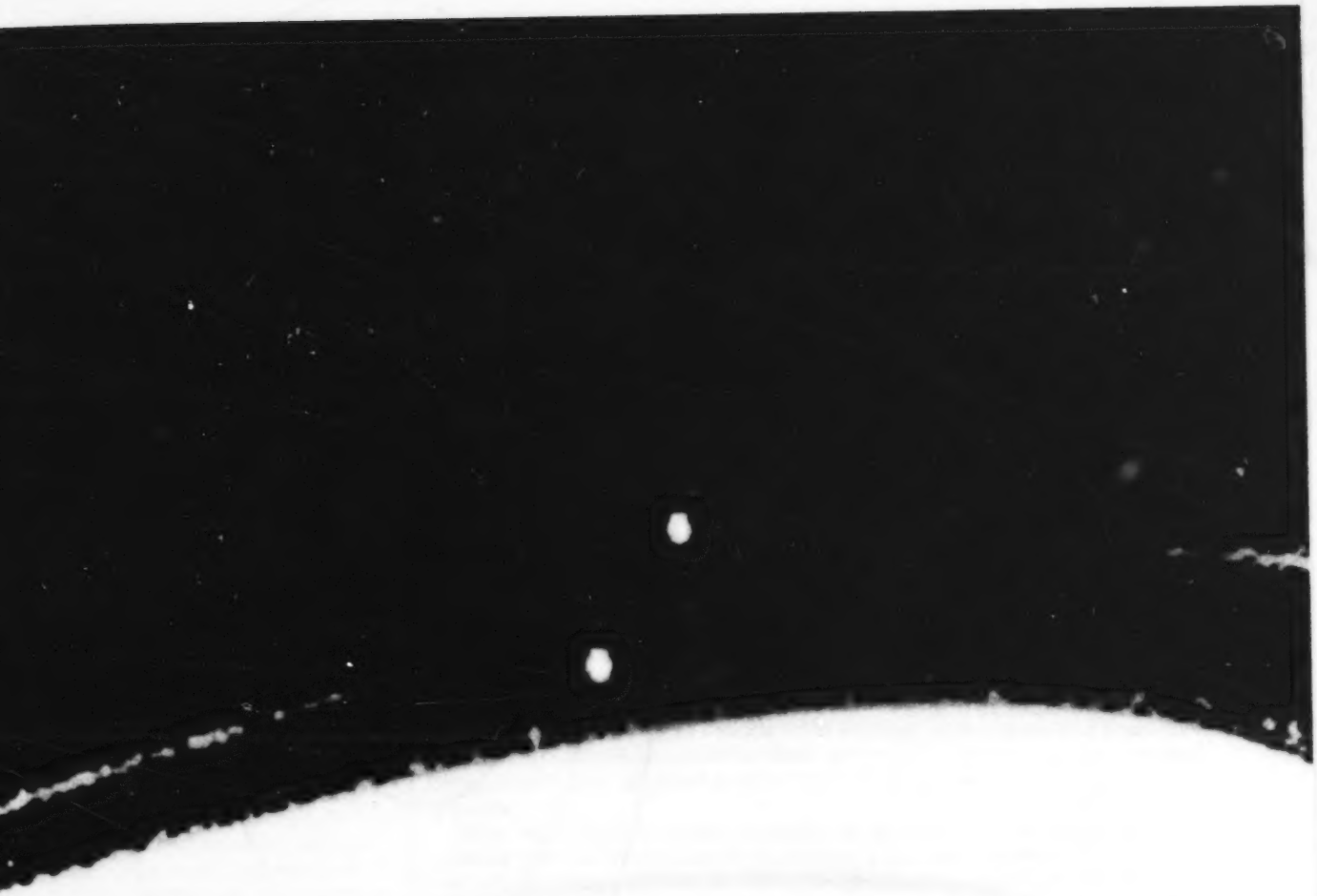
The radio signal from Uranus, nearly two billion miles away, is so faint that by the time it reaches Earth its energy is 100 billion times weaker than the power of an ordinary electronic watch. The antennas are therefore straining to hear this very weak signal against a natural background of radio noise in the sky. At the relatively close distances of Jupiter and Saturn, this was not a terrible problem. Voyager could send back its photographs and its data, all in the form of digital radio signals, at a very rapid rate. At Uranus, the transmission rate will have to be lower so that the ground-based receivers can separate the signals from the "noise."

Photographs demand the highest numbers of computerized "bits" of data, so engineers have had to come up with a way to lower data rates without sacrificing photo quality. The technique is called "data compression." Voyager photos are made of an array of dot-like picture elements, or pixels. Normally, each pixel would be assigned an absolute numerical brightness value using eight bits of data. But in order to "compress" the information from Uranus, each pixel will simply be compared to the one next to it—a single number, and fewer total bits of data.

January 24, 1986: Near Encounter

After eight and a half years of traveling at the speed of a rifle bullet, Voyager 2 will have less than one day to take close-up photographs of Uranus, its rings and moons. By comparison, the Jupiter and Saturn encounters were leisurely, with the major satellite and planetary

Saturn's slender F-ring, as photographed by Voyager 2 in 1981. Uranus' nine dark rings are even narrower, and may also have small "shepherding" moons that control their shapes.



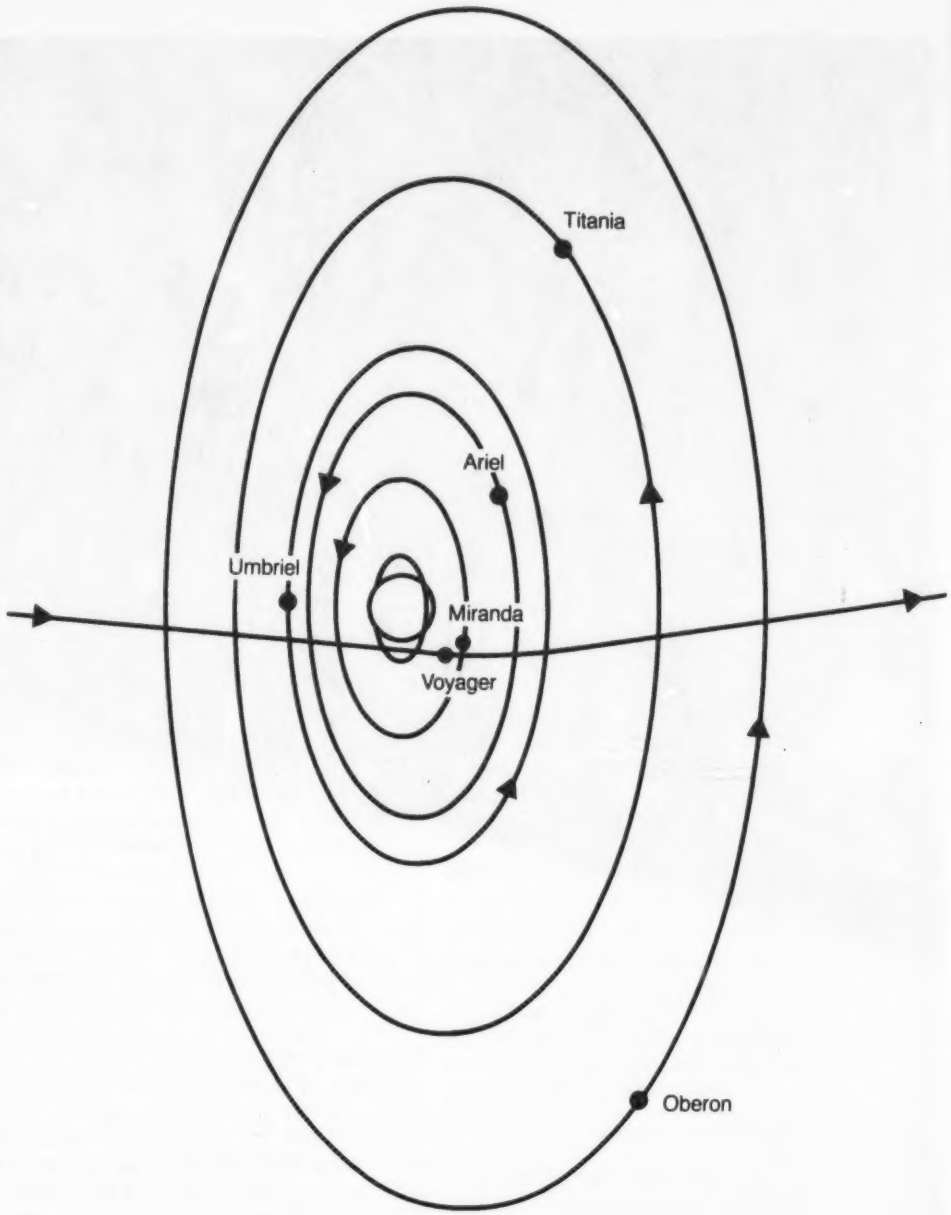
encounters spaced over several days. Most of the critical Uranus observations are crowded into a few hours.

The difference has to do, once again, with the planet's peculiar geometry. When Voyager flew through the Jovian and Saturnian systems, the satellites were laid out more or less flat, like marbles on a table, so that the spacecraft could study them one at a time. Flying into the realm of Uranus is like shooting through an archery target, with the planet at the bull's eye and the moons on the outer rings. Everything will happen at once, and the close encounter will be a busy time of shifting cameras and science instruments rapidly from one object to another.

A problem at Uranus that was not quite so severe at Jupiter and Saturn is the low level of illumination. In this remote part of the solar system, the Sun shines more like a bright star than our familiar yellow globe. As most photographers know, the dimmer the light, the more exposure time is necessary, and this is also true for Voyager's cameras.

But the spacecraft is moving very quickly, and the platform-mounted instruments need to shift to track their targets. If the camera platform were to move during these long exposures, its "stepping" motion might cause the images to smear, so Voyager engineers have developed a technique called Image-Motion Compensation, where the entire spacecraft, rather than the camera scan platform, is turned very slowly and smoothly to follow the target while the shutter is open.

Some of the highest resolution pictures of the Uranian moons will rely on this technique during the close flyby. At Miranda, for example, where the camera shutter must be left open for more than three seconds for each close-up image, the motion



As seen from Earth (to left of drawing) Voyager 2 will pass to the right of Uranus and behind it on January 24, 1986.

compensation technique allows objects as small as one kilometer to be resolved. The resolution would be closer to 50 km if the technique were not used.

In the final days before it reaches Uranus, Voyager's cameras will need to photograph the planet and rings in mosaics—overlapping frames—to ensure full coverage. Mosaics taken from different illumination angles will be useful in trying to determine the dimensions of the individual rings. They are known to be very narrow, only tens of kilometers wide or less, even narrower than the F-ring around Saturn. On the day of closest approach to Uranus, the photopolarimeter and ultraviolet spectrometer will record how starlight is blocked by the rings to help further characterize their size and makeup.

The Moons Revealed

As Voyager enters the realm of Uranus on the morning of January 24, 1986, it will be speeding ten times faster than a rifle bullet. The spacecraft is programmed to take both black and white and color images of the moons from varying Sun angles in order to reveal shading (and therefore vertical relief) on their surfaces. Scientists will be most interested to see how bright and how heavily cratered the moons are, and to what extent, if any, they have been reworked by geologic processes. It will be the first time anyone has ever seen the faces of the Uranian moons.

Voyager will make its closest approach (365,000 km) to Titania first, shortly after 7:00 a.m. Pacific time, or just three hours before it reaches Uranus. (Radio signals marking this and all spacecraft events will reach Earth some 2 hours and 45 minutes later.) Next up is outermost Oberon, at a distance of 470,000 km, followed by closer passes of Ariel (127,000 km) and Miranda (29,000 km). Umbriel will have to wait until three hours after Voyager's closest approach to Uranus for its near encounter, at a distance of 325,000 km.

Visual photography and photometry of the moons will be limited to their sunlit sides, but infrared observations of the entire disks may help to complete the scientific profile of each satellite. Only at Miranda will Voyager come close enough to significantly improve our knowledge of its mass, based on the moon's gravitational influence on the spacecraft.

Peering Through the Rings

Voyager will not pass *through* the rings of Uranus, but well outside them, more than twice as far from the planet as the outermost known ring, Epsilon. As it rounds the planet, Voyager will take close-up photographs and conduct nonvisible wavelength studies of the rings from changing Sun angles. At the time that Voyager actually

The Spacecraft: Robots into the Night

For its long-distance expedition, Voyager is equipped with its own nuclear power supply, a computer for making some limited decisions in the absence of a human operator, and a large dish antenna for calling home.

The spacecraft also is outfitted with an array of scientific instruments—its "senses"—that approximate what astronomers would take along were they to make the same trip.

Voyager's appearance is dominated by the wide dish antenna, which not only allows engineers to send instructions periodically to the spacecraft's computers, but also focuses the stream of data that is sent back to Earth during an encounter.

The antenna also serves as a science instrument at encounter time. When Voyager passes behind a planetary atmosphere or ring system as seen from Earth, radio signals beamed back through the atmosphere or rings carry information about their thickness and density.

Below the antenna are Voyager's brains, a ten sided "bus," where the spacecraft's three sets of twin computers are housed. These control the spacecraft's pointing, keep time with a master clock, and orchestrate events (based on programmed instructions loaded into the computer by radio command from the ground) during encounters.

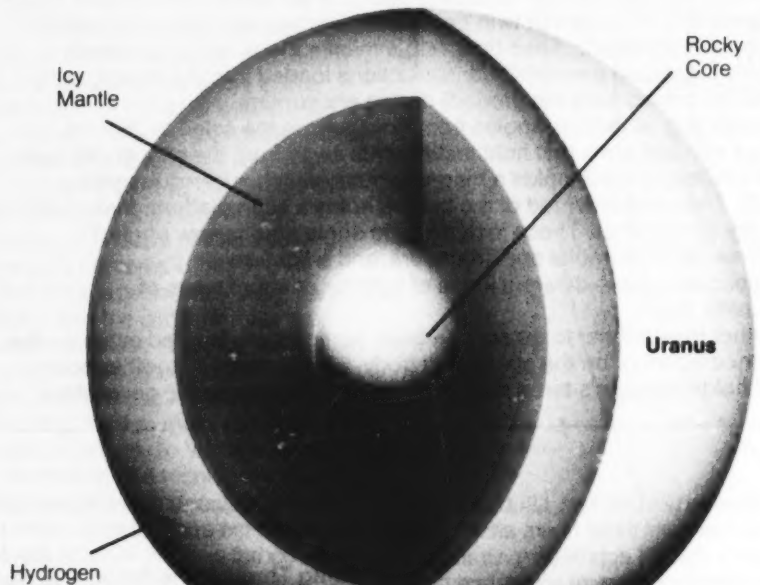
Projecting at various angles from Voyager are the science "booms," long extended arms that hold instruments away from the spacecraft body. The longest of these holds a magnetometer, which surveys magnetic fields. The most crowded of the booms holds a scan platform that contains Voyager's cameras. These include wide angle and narrow angle TV, infrared, and ultraviolet spectrometers, and a light-sensing photopolarimeter—different kinds of light for different types of scientific data.

Other instruments to detect energetic particles are located either on the science boom or on the spacecraft body. Finally, there is another boom that holds Voyager's three nuclear-powered thermoelectric generators.

crosses the plane of the rings, its plasma wave instrument will be listening for signs of tiny particle impacts that would signal the presence of very tenuous belts of material even at that distance.

Then, as the spacecraft crosses behind the rings as seen from Earth, it will conduct two critical experiments that may help to pin down the size of the ring particles. Both tests use "occultations," or the blocking of a signal by another body. Radio waves beamed from the spacecraft to Earth will be occulted, as will starlight from the opposite side of the rings seen by the spacecraft. By studying how these signals dim and brighten, scientists will be able to characterize the size of the particles. Finally, Voyager's cameras will be looking for "shepherding" moonlets that may control the configuration of the rings.

If many of the ring particles are small—about a micron in diameter—then there is a very good chance that when the spacecraft rounds the planet's dark side to look back in the direction of the Sun and Earth, it will see "forward scattered" radiation, like shafts of light in a smoky room. This may be the best illuminator of all for photographing the dark rings of Uranus.



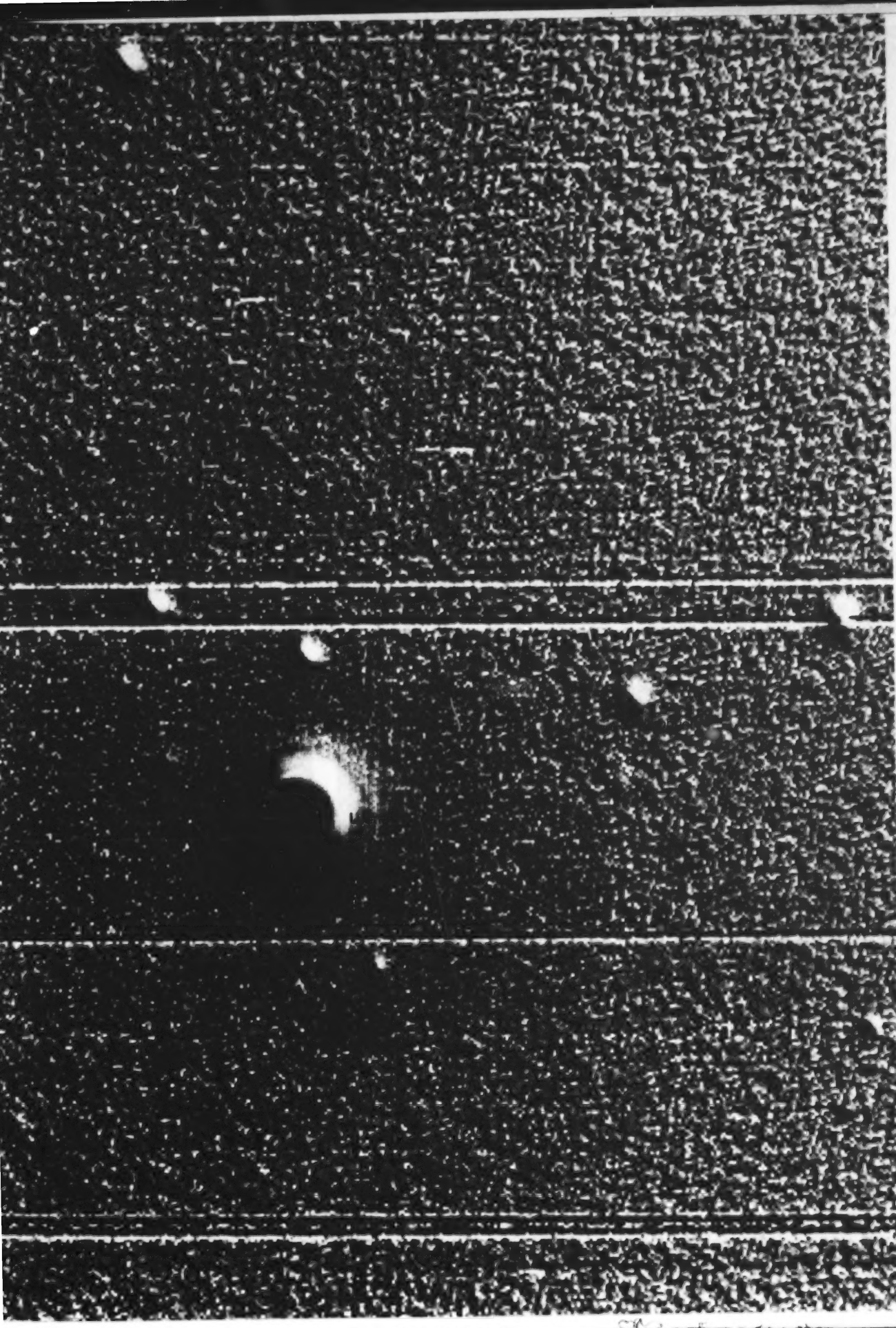
Uranus is believed to have a solid core surrounded by a mantle of ices, topped by a gas atmosphere.

Arrival at Uranus

As seen from Earth, Voyager 2 will pass on the right side of Uranus at a distance of 107,000 km at 10:00 a.m. Pacific Standard Time on January 24. Shortly after it rounds the planet, Voyager will make several important atmospheric studies that will supplement close-up photography. The ultraviolet sensor will look through the outermost edge of the atmosphere at the Sun and two other stars to take spectroscopic data on atmospheric composition. Radio waves beamed deep into the Uranian atmosphere toward Earth will carry information about the variations in pressure, temperature, and composition in the gas envelope surrounding the planet.

The Uranus magnetosphere also will be thoroughly investigated as Voyager cruises around the planet, surveying plasma (charged gas) fields. Rather than marking the end of the show, Voyager's passage behind Uranus into darkness marks the beginning of some of its most important investigations, including a search for auroras. On Earth, northern and southern auroras are caused when magnetic field lines running from pole to pole funnel solar wind particles into the upper atmosphere, which glows bright as a result. Because of Uranus' strange tilt, however, the south pole faces directly into the Sun. It is possible that on the dark side of the planet there may be no auroras, because the magnetic "tail" may be swept back away from the pole. Voyager will be searching the dark side for auroral activity, both in ultraviolet and visible light.

This computer-processed photo of Uranus, its rings and its moons was taken from Earth, using a charge-coupled device imaging system. It is the first clear photograph of the dark rings of Uranus.



After the Encounter: Darkside Views and a New Course

Leaving the newly "discovered" world ever farther behind, Voyager will continue to monitor the magnetic domain of Uranus, if there is one, on its outbound leg. Current models of the Uranian magnetosphere have the spacecraft crossing the field's boundary about four days after close approach to the planet.

If light is scattered forward from the rings, a planned sequence of "movies" during the post-encounter phase will show the orbital motion of the rings and their variation with time. Voyager's infrared sensor will also take parting-shot temperatures of the dark disk of the planet, to compare with similar data from the sunlit side.

The Voyager encounter with Uranus ends officially on February 25, 1986. Even before it is finished at Uranus, however, engineers will begin preparing the robot explorer for its next planetary encounter. On February 13, a three-hour firing of the spacecraft's thrusters will send it on the right path to fly over the north pole of Neptune on August 24-25, 1989. If all goes according to plan, Voyager 2 will, by the close of this decade, have completed the most far-reaching exploratory mission in history—the first survey of all the large planets of the outer solar system.

Classroom Activities

1. What were Voyager's major discoveries at Jupiter and Saturn?
2. Make a model of the Uranus system and rings. What are the "seasons" like as the planet makes its journey around the Sun? How do they differ from seasons on Earth?
3. Research theories about the formation of the planets. How do scientists explain the difference between the rocky inner planets and the gas giants of the outer solar system?
4. What are some of the problems with sending a spacecraft like Voyager so far away from the Sun and Earth?

Uranus and its five known moons, as seen through the 82-inch telescope of the McDonald Observatory. In 200 years of observation from Earth, no clear features have been identified in the planet's atmosphere.

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